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(54) Title: **IMPROVED ELECTRODE COMPOSITIONS**

(57) Abstract

An electrode composition for use as an electrode in a non-aqueous battery system. The electrode composition contains an electrically active powder in a solid polymer and, as a dispersant, a polyester polyamine copolymer that is electrochemically inert. The dispersant is electrochemically inert at 2.5-4.5 volts.

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## IMPROVED ELECTRODE COMPOSITIONS

5 This invention was made with Government support under contract DE-FC02-91CE 50336 awarded by the United States Department of Energy. The Government has certain rights in this invention.

Background of the InventionField of the Invention:

10 This invention pertains to battery components, including electrodes, and cells.

Description of the Related Art:

15 Storage batteries have a configuration composed of at least one pair of electrodes of opposite polarity and, generally, a series of adjacent electrodes of alternating polarity. The current flow between electrodes is maintained by an electrolyte composition capable of carrying ions across electrode pairs.

20 Non-aqueous batteries have certain distinct advantages over other types of storage batteries. They use, as anodes, light weight metals, such as alkali metals as for example, lithium metal, lithium oxides, lithium-aluminum alloys and the like which are at the far end of the electromotive series. These  
25 batteries have the potential for providing much higher specific energy (gravimetric) and volumetric energy densities (capacity per unit weight and volume, respectively) than other types of batteries, due to  
30 the low atomic weight of the metal and high potential

for forming a battery in conjunction with suitable positive electrodes far removed from the light weight metal electrode (the description herein will use batteries having lithium as the light weight metal anode although other light weight metals can be used) in the electromotive series. The battery can be formed in any conventional physical design, such as cylindrical, rectangular or disc-shaped "button" cells, normally of a closed cell configuration.

The battery components of positive electrode, negative electrode and an electrical insulating material capable of permitting ionic conductivity, such as porous separator membranes or a solid or gel polymer electrolyte located between the electrodes. Batteries formed of these components can be in the form of distinct alternating plates in a sandwich design or of a continuously spirally wound design as are well known.

As disclosed in copending U.S. patent applications, U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 8788), U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 8878), U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 9189), and U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 9190), co-assigned with the present application which teachings are incorporated herein by reference, methods and battery compositions have been developed which provide a solid polymer electrolyte-electrode composite suitable for light weight metal battery systems.

Briefly, the processes involve forming electrodes composed of active solid material which are co-

extruded with solid polymer electrolyte components to provide the resultant electrode-electrolyte composite.

Solid material suitable for forming anodes include, for example, carbons capable of intercalating the light weight metal ions within its crystal or other structure, such as graphite or coke and the like. Solid material suitable for forming cathodes are metal chalcogenides having a metal selected from Ti, Zr, Nb, Cu, Fe, Ta, V, Mn, C, Co, Ni and mixtures of these metals alone or together with intercalating metals, such as lithium or sodium. Preferred alkali metal (e.g. lithium) chalcogenides are those of manganese oxides, cobalt oxides, vanadium oxide or nickel oxides or mixtures thereof. The most preferred chalcogenides are lithium manganese dioxide and overlithiated manganese oxides. The electrochemically active material is normally used in combination with minor amounts of up to about 30 wt. % of a conductive carbon based on the total solids. The conductive carbon may be a carbon black, such as acetylene black and usually has a particle size range of from about 1 to 100 nm.

According to the embodiments disclosed, the solid polymer electrolyte is a blend of an electrolyte salt, a binder, and an organic liquid capable of solvating and forming an ionic complex with the salt. The salt is preferably a lithium salt selected from the group consisting of LiPF<sub>6</sub>, LiAsF<sub>6</sub>, LiCF<sub>3</sub>SO<sub>3</sub>, and LiClO<sub>4</sub>, and the like.

The liquids useful in forming the solid polymer electrolyte include the aprotic organic solvents, i.e., not prone to contributing a proton, such as ethylene carbonate, propylene carbonate, dimethyl

carbonate, diethyl carbonate, dimethyl adipate, tetramethylene sulfone, g-butyrolactone, dimethylformamide, dioctyl phthalate, and dibutyl phthalate and the like and mixtures thereof.

5       Polymers typically used in SPE's include polyacrylonitrile (PAN), poly(tetraethylene glycol diacrylate) (PEGDA), poly(vinylidene difluoride) (PVDF) and poly(vinyl pyrrolidinone) (PVP) and the like.

10       The various processes can be used to formulate composite electrolyte-anodes or electrolyte-cathodes, depending on the active electrode material utilized. The compounded composition typically is extruded into a desired shape, such as a sheet, which may be  
15       deposited onto a conductive current collector (foil, screen of metal) that can be cut into smaller sizes to form electrodes. The electrodes can then be assembled into batteries.

20       It is highly desirable to have a formulation that results in a final product having the desired characteristics, and one that is easily handled during processing. In extrusion processes, viscosity of the material is an important concern. The viscosity  
25       should be high enough to permit good mixing of the components to provide a homogeneous mass, while not being of such high viscosity to cause excessive back pressure in the extruder. At the same time the final product must have a high content of solid active  
30       particulate material to provide a suitable electrode.

      The formulations and extrusion processes optionally utilize additives to modify various properties of the materials during fabrication, such

as viscosity, and to enhance the characteristics of the final product. Typical of the additives used are dispersants. It might be assumed that a wide variety of dispersants might be useful to obtain the desired results. However, it has been found that, although there is a large number of dispersants available, most dispersants do not aid in enhancing the processing characteristics of the complex mixture of solid particulate material and solid polymer electrolyte (SPE) components. The SPE materials are generally fluid, low viscosity compositions under extrusion processing conditions. In addition, a selection of a particular dispersant is not obvious to the artisan when attempting to provide an extruded, highly-filled electrode, due to the many factors that influence the results one obtains with any particular dispersant. Among the factors that influence the results obtained are: (1) the solubility of the dispersant in the polymer electrode systems and/or organic electrolytes that are required in the application; (2) the chemical stability of the dispersant at the electrode potential realizing that many cells are operated at different potentials; (3) the stability of the electrochemically active and electrically conductive materials used in combination with a particular dispersant and under the conditions needed for fabrication; (4) the ability of the dispersant to allow or enhance binding of the active materials and other particulate material into a unitary structure at very low concentrations in order to provide an electrode with good performance; (5) the ability and ease of obtaining a uniform distribution of the dispersant with the binder and active material

of the electrode; (6) the ability of the dispersant to remain stable in an electrode capable of undergoing a multiplicity of charge-discharge cyclings; (7) the number and ease of the steps required to obtain the desired electrode; and (8) the safety, availability of the material, and cost.

#### Summary of the Invention

The present invention is directed to the addition of polyester/polyamine dispersants that are non-active and electrochemically stable (inert electrochemically) which produces a significant viscosity reduction to a feed mixture which has a high content of solid particulate active electrode material while providing an electrolyte-electrode composite product. This enables the obtainment of higher loadings of electrically active powder in the electrode, e.g.  $\text{LiMn}_2\text{O}_4$  in the cathode, or carbon in the anode. Preferably, the polyester/amine dispersant is electrochemically stable at 2.5 to 4.5 volts, most preferably 2.5-4.2 volts, as determined by standard procedures.

#### Detailed Description of the Invention:

The present invention is directed to an improved extrusion process to provide high energy electrode-electrolyte composite products. The present process has been found to achieve higher loading of solid active electrode product in which the dispersant is an electrochemically inert material; and which achieves

good flow-through processing properties within the extruder.

The electrode compositions to which the present invention has been found suitable are those described in co-pending application Serial No. \_\_\_\_\_ (Attorney Docket No. 8788), U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 8878), U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 9189), and U.S. Serial No. \_\_\_\_\_ (Attorney Docket No. 9190), which teachings are incorporated herein by reference. The present invention can be used most preferably in the process of the above application having Docket Nos. 9190, 8788, and 9189.

It has been unexpectedly found that the addition of certain dispersants which are classified as polyester/polyamine dispersants; - that is having ester and amine hydrophilic groups, provide a significant viscosity reduction during the extrusion processing of the materials; permit very high loading of solid active material; and provide an electrode in which the dispersant is an inert material therein. The polyester/polyamine dispersant must exhibit electrochemical stability (inertness) at an operating range of from 2.5 to 4.5 volts, most preferably from 2.5 to 4.2 volts, as determined by standard battery operating procedures.

Hypermer® KD1, available from ICI Americas, Inc. has been used to particular benefit. Hypermer® KD1 polyester/polyamine, when used as a dispersant in forming polymer electrode compositions, both anode and cathode, produces a significant viscosity reduction without deteriorating the electrochemical performance.

This unexpectedly enables the obtainment of higher loadings of electrically active powder in the cathode or in the anode, e.g.,  $\text{LiMn}_2\text{O}_4$ , in a cathode, or carbon in an anode.

5           The dispersant can be premixed with one or more of the components used in forming the desired composite electrolyte-electrode. Normally the dispersant is added as part of the initial feed mixture where more than one feed stream is used. The dispersant is  
10           preferably added to the solid active material. The dispersant should be used in from about 1 to about 3 percent of the total composition.

          The preferred polymeric dispersant, is Hypermer® KD1. Other Hypermer dispersants having different  
15           solubility and stability characteristics have not been found suitable in achieving the desired result. For example, a series of these dispersants are known to have the following characteristics:

20           (1) HYPERMER® KD1 for use in medium polarity solvents, e.g., ethers, ketones, THF, chlorinated hydrocarbons, and blends of these solvents.

          (2) HYPERMER® KD2 for use in highly polar solvents, e.g., ethanol, iso-propanol, 2-ethoxy  
          ethanol and some aqueous systems.

25           (3) HYPERMER® KD3 and HYPERMER® KD4 for use in non-polar systems, e.g., mineral spirits, toluene, xylene, paraffin waxes and oils. Additional characteristics of certain hypermer products are shown  
30           in the following Table A:

TABLE A  
Physical Characteristics

HYPERMER® Polymeric Dispersant	Appearance	Melting Point °C <sup>1</sup>	Specific Gravity	Viscosity (cps)	Effective Solvent Polarity Range
KD1	Tan colored flakes	Softens 60°C	1.05	N/A	Medium Polar
KD2	Straw colored liquid	N/A	1.02	200-320 at 20°C	Highly Polar
KD3	Amber liquid/ paste	Pourable 25°C	0.92	1600-2200 at 35°C	Non-polar

The nature of the invention will be made clearer  
by the following examples:

Example 1

This example shows how the viscosity of a solid  
polymer electrolyte (SPE) mixture (without the  
electrically active component) is determined.

A solid polymer electrolyte composition according  
to the present invention was prepared, as follows:

Solid Polymer Electrolyte (SPE)

wt. % Component

- 44 Ethylene Carbonate (Aldrich)
- 44 Propylene Carbonate (Grant Chemicals)
- 6 Polyacrylonitrile (Eastern Chemical)
- 6 Lithium (bis) trifluoromethanesulfonimide (3M)

The mix was heated to 120°C while mixing to form a  
uniform mixture.

The viscosity of the mixture was determined as follows:

A Brookfield RVT-DV-II viscometer was used with a "Thermosel" attachment. The temperature was 125°C. A number 27 spindle was used. The viscosity of this mixture was found to be 150 cp at shear rates between 6.8-34 sec<sup>-1</sup>.

#### Example 2

This example compares the viscosity of the basic SPE mixture of Example 1 with the same mixture containing an electrically active component (LiMn<sub>2</sub>O<sub>4</sub>), such as would be used to form an electrolyte-electrode composite according to the present invention.

LiMn<sub>2</sub>O<sub>4</sub> powder (obtained from the Davison Chemical Division of W.R. Grace) (20.17 parts per 10 parts SPE) was added to the mixture of Example 1, and the viscosity was determined as in Example 1. The viscosity was found to have increased to 12,500 cp at 6.8 sec<sup>-1</sup>. At 3.4 sec<sup>-1</sup>, the viscosity was 16,400 cp, and at 0.85 sec<sup>-1</sup>, the viscosity was 76,800 cp.

#### Example 3

This example shows the effect of various organic-soluble dispersants on the viscosity of the electrolyte-electrode mixture of Example 2.

Various commercially available dispersants were added to the mixture of Example 2, and the viscosity determined as in Example 1. The results are summarized in Table I.

Table I

<u>Dispersant</u>	<u>Dosage</u> <u>(g/10 g SPE =</u> <u>20.17 g LiMn2O4)</u>	<u>Viscosity</u> <u>(cp)</u>	<u>Shear</u> <u>Rate</u> <u>(sec<sup>-1</sup>)</u>
Hypermer® KD1 (ICI)	0.2	6,200	3.4
Hypermer® KD3 (ICI)	0.2	20,200	3.4
OLOA 1200 Chevron	0.2	21,800	3.4
Hypermer® KD2 (ICI)	0.2	57,200	0.85

These results show that only the Hypermer® KD1  
produced a significant viscosity reduction, whereas  
the other dispersants actually increased viscosity.

#### Example 4

This example shows the effect of the addition of  
acetylene black to the SPE mixture, such as would be  
added to form an electrolyte-electrode composite  
according to the present invention.

Acetylene black (Chevron) (1.36 parts) was added to  
20 parts of SPE from Example 1. The rheology of this  
mix was determined at 125°C using a number 29 spindle.  
The results are summarized in Table II below.

Table II

Shear Rate ( $\text{sec}^{-1}$ )	Viscosity (cp)
1.7	180,000
0.85	276,000
0.34	468,000
0.17	772,000

Example 5

5

This example shows the effect of Hypermer® KD1 on the viscosity of the mixture of Example 4.

Hypermer® KD1 (0.2 parts) was added to the mixture of Example 4, and viscosity measured at 125°C with a number 29 spindle. The results are summarized in Table III below.

10

Table III

<u>Shear Rate (sec<sup>-1</sup>)</u>	<u>Viscosity (cp)</u>	<u>% Reduction</u>
1.7	32,600	82
0.85	51,000	82
0.34	115,000	75
0.17	240,000	69

- 5           The results show a 69-82% viscosity reduction with Hypermer® KD1.

Example 6

- 10           This example shows the effect of  $\text{LiMn}_2\text{O}_4$  addition on the viscosity of SPE and acetylene black.
- To the mixture described in Example 4 (33.6 parts SPE, 1.9 parts acetylene black) was added 25.5 parts  $\text{LiMn}_2\text{O}_4$ . The viscosity was determined at 125°C with a
- 15           number 29 spindle and is summarized in Table IV below.

Table IV

Shear Rate ( $\text{sec}^{-1}$ )	Viscosity (cp)
1.7	142,000
0.85	233,000
0.34	370,000
0.17	750,000

Example 7

5 This example shows the effect of Hypermer® KD1 on the mixture of Example 6.

10 To the mixture of Example 6 was added 0.67 parts of Hypermer® KD1. The viscosity was determined as in Example 6. The results are summarized in Table V below.

Table V

Shear Rate ( $\text{sec}^{-1}$ )	Viscosity (cp)	% Reduction
1.7	24,400	83
0.85	24,400	89
0.34	64,000	83
0.17	134,000	83

15 These results show that Hypermer® KD1 reduces the viscosity of a cathode mixture 82-90%.

Example 8

This example shows the effect of Hypermer® KD1 on the viscosity reduction of the anode formulations. Table VI lists the formulations of each anode sample which were tested, the sample mixing conditions using the Haake Torque Rheometer, the sample viscosity measured at four different shear rates using the Instron capillary rheometer, and the sample viscosity drop due to the addition of the Hypermer® KD1 at 2200 1/sec shear rate.

- a) As shown in Table VI, Row 1 and 2, adding 1.5wt% of Hypermer® KD1 to an anode mixture having 45 v% solid loading results in a 46% viscosity reduction.
- b) As shown in Table VI, Row 1 and 3, adding 2.0 wt% of Hypermer® KD1 to an anode mixture having 45 v% solid loading results in a 62% viscosity reduction.
- c) As shown in Table VI, Row 4 and 5, adding 1.66 wt% of Hypermer® KD1 to an anode mixture having 50 v% solid loading results in a 9% viscosity reduction.
- d) As shown in Table VI, Row 4 and 6, adding 2.6 wt% of Hypermer® KD1 to an anode mixture having 50 v% solid loading results in a 48% viscosity reduction.

TABLE VI

The effect of Hypermer® KD1 on the anode viscosity drop.

## ANODE HAAKE/INSTRON DATA

Line No.	FORMULATION				MIXING CONDITION				Instron visc. (poise) at 125°C at shear rate (1/sec)				% visc drop at 2200 (1/sec)
	solid		wt% Hypermer KD1	Temp (°C)	rpm	time (min)	220	730	2200	7300			
	vol%	wt%											
(1)	45.0	58.0	42.0	0	115	110	12	2100	1060	534	245	0	
(2)	45.0	58.0	41.5	1.5	115	110	10	1395	508	290	112	46	
(3)	45.0	58.0	40.0	2.0	118	110	10	1245	480	204	103	62	
(4)	50	63.0	37.0	0	115	110	15	3260	1500	760	400	0	
(5)	50	63.0	35.34	1.66	115	110	12	3840	3560	680	345	9	
(6)	50	63.0	34.4	2.66	115	110	20	1600	686	396	250	48	

Example 9

5           This example shows the effect of Hypermer® KD1 on  
the viscosity reduction of the cathode formulations.  
Table III lists the formulations of each cathode  
sample being tested, the sample mixing conditions  
using the Haake Torque Rheometer, the sample viscosity  
measured at four different shear rates using the  
10       Instron capillary rheometer, and the sample viscosity  
drop due to the addition of the Hypermer® KD1 at 2200  
1/sec shear rate.

- 15           a) As shown in Table VII, Rows 1 and 2, adding  
2.0 w% of Hypermer® KD1 to a cathode mixture  
having 45 v% solid loading results in a 12%  
viscosity reduction.
- 20           b) As shown in Table VII, Rows 3 and 4, adding  
3.0 w% of Hypermer® KD1 to a cathode mixture  
having 48 v% solid loading results in a 50%  
viscosity reduction.
- 25           c) As shown in Table VII, Rows 5 and 6, adding  
3.0 w% of Hypermer® KD1 to a cathode mixture  
having 50 v% solid loading results in a 59%  
viscosity reduction.
- d) As shown in Table VII, Rows 5 and 7, adding  
4.0 w% of Hypermer® KD1 to a cathode mixture  
having 50 v% solid loading results in a 61%  
viscosity reduction.

TABLE VII  
The effect of Hypermer® KD1 on the cathode viscosity drop.

## ANODE HAAKE/INSTRON DATA

Line No.	FORMULATION				MIXING CONDITION						Instron visc. (poises) at 125°C at shear rate (1/sec)		% visc drop at 220°C (1/sec)
	solid		WASPE	W&S Hypermer NDI	Temp (°C)	rpm	time (min)	220	730	2200	7300		
	vol%	wt%											
(1)	45.0	71.0	25.0	0	120	110	12	3320	1220	620	300	0	
(2)	45.0	71.0	27.0	2.0	120	110	12	2200	1216	545	246	12	
(3)	48.0	73.0	27.0	0	120	110	12	5000	2170	1130	470	0	
(4)	48.0	73.0	24.0	1.0	120	110	10	2560	1150	570	300	50	
(5)	50	75.0	25.0	0	120	50	30	6000	2850	1400	450	0	
(6)	50	75.0	22.0	1.0	120	110	20	3270	1150	656	310	59	
(7)	50	75.0	21.0	4.0	120	110	20	2590	1200	622	320	61	

Example 10

This example shows the effect of Hypermer® KD1 on the anode film processability and film quality. Table VIII lists the formulations used in the extrusion/calendering process and the processing results in terms of film thickness (Film H), film width (Film W), and die flow uniformity and film dimensional stability. Table IX gives the corresponding extrusion/calendering conditions used for each of the runs.

- a) As shown in Table VIII, row 1 and 2 adding 0.5% Hypermer® KD1 to an anode mixture having 45 v% solid loading reduced the blank thickness from 15-20 mil to 10 mil, and improved the die flow uniformity, and the film width dimensional stability.
- b) As shown in Table VIII, row 3 and 4, adding 1.66% Hypermer® KD1 to an anode mixture having 50 v% solid loading greatly improve the processability. Without Hypermer® KD1 this material was not extrudable due to a very high viscosity caused by the high solid loading. Adding 1.66% Hypermer® KD1 achieved a film having 4-5 mil thick and 7-8 inches wide.

TABLE VIII - Effect of Hypermer® KD1 on the Anode Film Processing.

Line No.	FORMULATION				RESULTS			
	Solid Loading	Hypermer® VA	Blank H (mil)	Film H (mil)	Blank W (inch)	Film W (inch)	Die Flow	Film Dimension Stability
(1)	45 VA (58 WA)	0	15-20	3-5	7-8	Varied	Pull die flow, but uneven edge tearing rate to a slow flow rate.	Film width varied.
(2)	45 VA (58 WA)	0.5	10	4-5	4	4	Pull die flow, fairly even and stable.	Film width was fairly stable at 4 inches.
(3)	50 VA (62 WA)	0	-	-	-	-	Extruder jammed.	-
(4)	50 VA (62 WA)	1.66	25-30	4-5	7-8	varied	Pull die flow, uneven, edge slow.	Film width varied.

TABLE IX - Anode Extrusion and Calendaring Conditions<sup>1</sup>

Line No.	FORMULATION	EXTRUDER				DIE			CALENDAR		
		Temp (1-5) (°C)	Screw (RPM)	Feed (g/hr)	TC (°C)	Pressure (psi)	Temp (°C)	GAP (mil)	Roll T (psi) top/bot	Roll GAP (mil)	Roll V (ft/min)
(1)	45 VA (58 WA) 0 VA Hypermer® KD1	115-115-115-110-75	130	17-25	14	760	121	3	45/240	1-1.5	8-15
(2)	45 VA (58 WA) 0.5 VA Hypermer® KD1	123-123-120-95-75	130	17-25	10	650-530	125	1.5-2	45/240	1-1.5	20
(3)	50 VA (62 WA) 0 VA Hypermer® KD1	120-120-120-95-75	110	17-25	12	2100 Extruder jammed	125	3	45/240	1-1.5	8-15
(4)	50 VA (62 WA) 1.66 VA Hypermer® KD1	121-121-121-95-75	130	17-25	11	810	126	3	45/240	1-1.5	8-15

<sup>1</sup> - The corresponding processing results are given in Table VIII, under the same line number.

Example 11

This example shows the effect of Hypermer® KD1 on the cathode film processability and film quality.

Table X lists the formulations used in the extrusion/calendering process and the film processing results in terms of film thickness (Film H), film width (Film W), as well as die flow uniformity and film dimensional stability. Table XI gives the corresponding extrusion/calendering conditions used in each of the runs.

- a) As shown in Table XI, row 1 and 2, adding 2% Hypermer® KD1 to a cathode mixture having 45 v% solid loading improved the die flow uniformity thus improved the film width stability.
- b) As shown in Table XI, row 3 and 4, adding 3.0% Hypermer® KD1 to a cathode mixture having 48 v% solid loading greatly improve the processability. Without Hypermer® KD1 the die flow was very uneven, and large portion of the die was blocked due to high viscosity of the material. Adding 3% Hypermer® KD1 greatly reduced the die blocking, improved the die flow uniformity, and stabilized the process. We were able to get a film with 7 inch wide and the process was fairly stable and lasted for 20 minutes.

TABLE X  
Effect of Hypermer® KDI on Cathode Film Processing

Line No.	POPULATION		RESOURCES				
	Solid Loading	Hypermer® VA	Blank H Mill	Film H Mill	Blank W Inch	Film W Inch	Film Dimension Stability
(1)	45.4 VA (71 VA)	0	12-15	4-7	4.5	varied	Film width varied considerably. Die blocked. Uneven flow. Strips.
(2)	45.4 VA (71 VA)	2	10-12	8-9	6	6.5	Film width was fairly stable at 6.5 inches. Die blocked.
(3)	48 VA (73 VA)	0	15-16	4-7	4-2	varied	Die blocked. Severe, uneven flow.
(4)	48 VA (73 VA)	3	13-15	9-10	7	7.5	Film width was fairly stable at 7.5 inches. The process continued for 20 minutes.

TABLE XI  
Cathode Extrusion and Calendaring Condition

Line No.	POPULATION	EXTRUDER				DIE				CALENDER		
		Temp (1-5) (°C)	Screw Speed (rpm)	Temp (6-7) (°C)	Temp (8-9) (°C)	Pressure (psi)	W (in)	Temp (°C)	Gap (mil)	Roll T (°F)	Mip gap (mil)	Roll V (ft/min)
(1)	45.4 VA (71 VA) 2% Hypermer® KDI	118-119-110-95-75	130	45-60	49-56	450-550	128	3	45/240	1-2	1-2	13
(2)	45.4 VA (71 VA) 2% Hypermer® KDI	120-120-120-95-75	130	37	10	380-400	115	2-3	45/240	1-2	1-2	9-10
(3)	48 VA (73 VA) 0% Hypermer® KDI	134-137-124-117-124	160	60-50	46	2100-900	130-135	3	45/240	1-2	1-2	
(4)	48 VA (73 VA) 3% Hypermer® KDI	118-118-110-95-75	130	38-60	15	670-690	120	3	45/240	1-2	1-2	11-13

10. The corresponding processing results are given in Table X under the same line number.

Example 12

This example shows that Hypermer® KD1 does not adversely affect cell performance. Cells were prepared with and without Hypermer® KD1. The data in the following Table XII are the average performances of three control cells and three Hypermer® KD1 cells, respectively. Both cells were made with 5 mm coke (Conoco). At cycle 30, the Hypermer® KD1 cells have an average capacity of 6.3 mAh, with a current efficiency of 100% (within the error of the measurement). There has been no measurable degradation since cycle 5.

Table XII

Cell	Theoretical Capacity (LIC)	Capacity (LiMnO <sub>2</sub> ) (100mAh/g)	Capacity Cycle 1	Efficiency Cycle 1	Capacity Cycle 5	Efficiency Cycle 5
Control	22 mAh	11.3 Mah	6.2 mAh	54.6%	7.8 mAh	96.8%
Control + 2% Hypermer® KD1	13.7	12.1	4.7	54.3	6.3	98.7

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. The present invention is to be limited not by the specific disclosure herein, but only by the appended claims.

What is Claimed is:

1. An electrode composition containing an electrically active powder in a solid polymer and, as a dispersant, a polyester polyamine copolymer that is electrochemically inert.

2. A composition according to claim 1 wherein said electrode is a cathode and said electrically active powder is lithium manganese dioxide ( $\text{LiMn}_2\text{O}_4$ ) or overlithiated manganese oxide.

3. A composition according to claim 2 wherein said composition comprises ethylene carbonate, propylene carbonate, polyacrylonitrile, lithium (bis)trifluoromethanesulfonimide,  $\text{LiMn}_2\text{O}_4$ , acetylene black, and said dispersant.

4. A composition according to claim 1 wherein said electrode is an anode and said electrically active powder is carbon capable of having lithium ion intercalated within its structure.

5. The composition according to claim 1 wherein said dispersant is electrochemically inert at 2.5-4.5 volts.

6. The composition according to claim 1 wherein said dispersant is electrochemically inert at 2.5-4.2 volts.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/08032

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H01M 4/62

US CL : 429/ 214, 215, 217, 218, 250

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/ 214, 215, 217, 218, 250

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
Please See Extra Sheet.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,358,801 A (BRODD) 25 October 1994, col. 14, lines 9-21; col. 6, lines 26-60; col. 15, lines 31-35.	1
A	US 3,918,989 A (GILLMAN et al.) 11 November 1975	1-6
A	KIM, YOUNG-WOOK et al., Tape Casting of Silicon Nitride, Materials Research Society Fall Meeting, Boston, MA, November 1992. (Abstract)	1-6

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reasons (see specification)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"A"

document member of the same patent family

Date of the actual completion of the international search

17 JULY 1997

Date of mailing of the international search report

26 SEP 1997

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US97/08032

## B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

CA, WPIDS, INSPEC, COMPENDEX, USPATFULL

search terms: Hypermer<sup>7</sup>; polyester<sup>8</sup> or polyamine<sup>8</sup>; electrode<sup>8</sup> or cathode<sup>8</sup> or anode<sup>8</sup>; electrochem<sup>9</sup> (3a) (inert or nonconduct<sup>7</sup> or conduct<sup>7</sup>)